In the hot

For the third feature in Plant Engineer's instrumentation and control series, Brian Tinham puts the heat on temperature sensing, standards and selection criteria

Pointers

- Thermocouples offer the widest temperature range and are best for industrial fast response applications
- RTD devices offer higher accuracy and lower drift, but tend to be more fragile
- Thermowells provide the pressure-tight, protective process entry points and are critical assemblies
- PSSR does not pertain, but ASME VIII and PD 5500 set out requirements
- A little extra money goes a long way when it comes to transmitter functionality

So we've got pressure, flow and level measurement under our belts (see Plant Engineer, November/December 2008 and January/February 2009). Time to move on to temperature – and although there are very few sensing technologies, there is huge variety in terms of sensor, probe and thermowell constructions, the wiring and the transmitters – all of which play vital parts in getting reliability, precision and safety.

From a plant engineer's perspective, given that about half of all measurements are of temperature, getting this right is important. Which is why specialists still prosper, and why there are entire volumes given over to thermocouple and resistance thermometry, as well as controllers. Go to TC, for example (www.tcdirect.co.uk/reference.asp), and you'll see the extent of coverage – theory, international reference tables and tolerances, colour codes, connectors, standards etc.

Starting at the raw sensing end, there are just two common technologies: thermocouples and resistance thermometers (RTDs) – although we ought also to mention thermistors (more usually used for inrush current limiting) and also now inline infrared sensors (for maintenance applications).

Thermocouples offer by far the widest temperature range (typically up to +1800°C) and are generally best where fast response is required, or in harsh applications where vibration or rapid shifts in temperature are problems. Meanwhile, RTD devices cover from -200°C to +600°C (special versions take that to +850°C), and offer greater accuracy and lower drift – although they are limited by their relatively fragile construction and possible problems with contamination at high temperatures.

Going a little deeper, thermocouples rely on the thermoelectric effect – variously described as the Seebeck, Peltier and Thomson effect – in which a voltage is generated when any conductor is subject to a thermal gradient (and vice versa). Theoretically, that's measured by using a dissimilar metal (with a different characteristic) to complete the circuit, and detecting the voltage between the two legs at the junctions – one the hot (measurement) location, the other the cold (reference). However, in industrial plant, since a reference is rarely feasible, electronics are used to compensate (simulate the cold junction).

Thermocouple types

Sounds complicated? It isn't: thermocouples are the simplest and cheapest of the temperature sensors and – although accuracy is limited and it's possible for the uninitiated to forget (or even create) 'system errors' – they're almost always the first choice. They're also available in a range of standard types (IEC 60584.1 pertains) to suit most plant applications (in terms of range, sensitivity and environmental compatibility), with equally standard (and coded) extension wires and connectors, as well as probe types and protective sheaths (IEC 60584.2 defines output tolerances and IEC 60584.3 details extension and compensating cable).

Type K (chromel-alumel), for example, although among the oldest, are the most common, covering from –200 to +1,350°C, with adequate sensitivity for the vast majority of applications. Then there are types E, J and N. In brief, E offer higher output and characteristics suited to cryogenics; J are mostly used in like-for-like replacements on older plant; and N (nicrosil-nisil) – effectively the newer (but more expensive) type K – are good for elevated temperatures, because of their relative stability and resistance to oxidation.

Then at the top end are types B, R and S, which use platinum or platinum-rhodium combinations to allow greater stability in the higher temperature

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ranges (to 1,800°C), although with greatly reduced outputs. You'll also see types T, C and M. If in doubt, consult a specialist – and be aware that, with thermocouples such as type K that use magnetic material, there is a step change in output at the 'Curie piont', so your readout needs to be calibrated accordingly. For more information, go to: http://en.wikipedia.org/wiki/Thermocouple

RTD sensing

Moving on to RTDs, these measure the change in resistance of a conductor with temperature – almost always platinum, because of its virtually linear response. There are three types: general-purpose wire-wound ceramic; wire-wound glass for extreme conditions; and thin film devices, where platinum is deposited onto a ceramic former – making them small, low thermal mass and (in that sense) most like thermocouples. IEC 60751 is the standard for output tolerances and colour codes – also defining Class A and B, the former being the most accurate.

Issues to consider (although they're usually taken care of by the instrument manufacturer) include wiring configuration and self-heating problems. On the wiring side, you'll come across two-, three- and four-wire configurations in increasing order of accuracy. Two-wire versions are the simplest, but have the disadvantage of measuring the resistance of the connecting wires, as well as the sensor – negating some of the benefit of choosing an RTD. Three-wire versions are much better, because lead resistance is approximately cancelled out, making the sensors good for remote reading up to 600m. But four-wire units are the Rolls-Royce of RTD craft – the Kelvin (as opposed to Wheatstone bridge) version enabling zero errors from the lead wires.

Then there are choices around dc versus ac: ac eliminates thermal emf errors, but you're measuring impedance, meaning it's important to choose a non-inductive sensor; dc measures true resistance only, but thermal emfs can be a problem. Finally, on self-heating, the issue is that, since a current is required to measure resistance, the sensor is liable to heating, which, unless dissipated, will show up in the measurement and result in errors.

So far, so good, but whichever sensor type and configuration you choose, the next big issue is protection: not just the probe sheath (with its potted connections and electrical insulation), but, especially on process plant, the thermowell – the pressure-tight tube that protects the sensor from the process. This is a critical assembly, not least because, while it needs to conduct heat well, it also penetrates the piping or vessel, so must not compromise safety.

As Andrew Dunbabin, product manager for high temperature products at ABB, says: "The danger is that a tube sticking into a process pipe or vessel could present a point of weakness, if not properly specified. Any failure could result in damaged plant, or even injury and prosecution. So it's vital that thermowells are manufactured and specified correctly to withstand pressure and mechanical stresses, as well as corrosive or erosive media."

As a result, for arduous duties they are typically machined from a single piece of material, while fabricated types are restricted to general usage. So, for example, drilled units can usually withstand up to 550°C and 600bar, while welded versions (to the American ASME IX standard, or one of several European versions) are suitable only for up to 400°C and 80bar. There's also the matter of temperature compatibility: while base metal thermocouples can

Above: ABB temperature sensors used in the production of aeroplane landing gear at Messier Dowty's Staverton plant
Left: Emerson temperature transmitter in process

Technology on the horizon

Oxford RF Sensors, a spin-off from the Clarendon Laboratory (the physics centre at Oxford University), is working with novel RF sensors designed to interrogate solid and fluid material properties where existing techniques can't cope. The technology harnesses frequencies in the MHz to low GHz regions and is aimed at detecting materials' magnetic and electric susceptibility and permittivity respectively, in real time.

Now past the proof of concept stage, its RF sensors are currently being licensed to companies around the world for a range of measurements, including temperature and phase change in materials. As for applications, thoughts are turning to plastic extruder machine monitoring, for example – often problematic with conventional sensing techniques.

Says Ross Walker, CEO of RF Sensors: "Susceptibility [of a solid] changes linearly with temperature until the material reaches its plastic stage, when there are significant changes. Then, once it is in the liquid phase, behaviour again becomes linear."

Inline infrared optics

Rugged inline process infrared imagers are now emerging at costs well below the early devices – although still in the thousands of pounds range. Micro-Epsilon's PI, for example, covers –20 to 100°C, 0 to 250°C and 120 to 900°C, with system accuracy claimed at ±2°C or ±2%.

Similar to other industrial thermal imaging cameras, the PI uses an uncooled micro bolometer focal plane array, with 160 x 120 pixels. Exchangeable lenses of 31 degrees and 9 degrees field-of-view enable temperatures to be measured across a variety of distances.

Says Micro-Epsilon managing director Chris Jones: "Many process plants have maintenance technicians who patrol certain areas, using expensive handheld thermal cameras. PI can be installed in a fixed position, next to a critical part of the process, to constantly monitor a target material or object."

cope with 1200°C when protected by metal thermowells, you'll need a ceramic thermowell for a precious metal sensor at higher temperatures.

The accepted rule is that the thermowell be specified to match or exceed construction of the pipeline or vessel. There is no thermowell equivalent to PSSR (Pressure System Safety Regulations), but pressure vessel and piping standards, such as ASME VIII and the European PD 5500, do set out requirements for pressure-retaining parts. They're not legally binding, but, as Dunbabin says: "It would be hard to justify any deviation from them, especially following an incident."

And much the same applies to flange fittings, ANSI B16.5 (or DIN 43772) being the standard, which in turn refers to secondary standards for material specification – such as ASTM A182 for austenitic steels and ASTM A105 for carbon steels. Note that, unlike thermowell stems, flanges must not be machined from bar stock, but from plate or forged material, hot worked into shape before being machined. Also, when it comes to sizing, any flange supplied under the ASME codes must have the size and rating stamped on it. Again, PD 5500 is the European standard, currently (but not yet) on its way to becoming a European Directive.

One more point on pipelines: mechanical stress, due to fluid flow. The concern is that, at high flows, the thermowell sheds Von Karmen vortices – which are bad news if their frequency approaches the resonant frequency of the thermowell. ASME PTC 19.3 is the relevant standard here, providing methods for calculating their frequency and safety margins. The real worry is where pipelines are transporting a gas, because then flow may be high and damping low. The main solutions are shorter, thicker thermowells and/or velocity collars, which change the resonant frequency of the thermowell. The latter form a tight fit where the stem meets the pipe wall, effectively shortening the unsupported length of the stem – but they're not cheap.

Field-mounted transmitters can cope with multiple sensor inputs and extremes of industrial environments

Finally, there's the transmitter, fitted to a connection head to an extension tube from the thermowell – and designed to save on long lengths of expensive and error-inducing extension cable. Transmitters can be housed in the head itself (preassembled and pressure-tested), mounted nearby in the field or remotely in a control panel. Head-mounted transmitters, for general process requirements, are usually built into the housing; field-mounted versions can cope with multiple inputs and are enclosed for mounting in anything from cold rooms to oil rigs; and control panel transmitters are DIN rail- or rack-mounted.

Analogue or digital?

Whichever you choose, the only mechanical issue is long-term stability in the face of factors such as vibration, contamination, humidity and changes in ambient temperature. But the real deal today is whether to go for 4–20mA analogue output, HART (where a digital signal is superimposed on the 4–20mA signal) or one of the full fieldbus standard digital plant types – the latter two both delivering diagnostics for the sensor and internal electronics.

You might imagine that, if you want cheap, you'd go for analogue – and at £60–80 for the transmitter, you'd be right. But the next tier – head-mounted HART with no frills – only cost £100–150, and now you've got instrument diagnostics. Beyond that are full digital transmitters (more expensive again), those with options such as local displays and finally wireless versions – which, although double the price, cut out expensive wiring and make otherwise impossible measurements possible.

The more advanced transmitters may also offer enhancements, like transmitter/sensor matching for RTDs. That might sound like a luxury, but, as Rico Yao, Emerson's business manager for temperature products, points out, every RTD is slightly different. So getting the calibration precise, using factory-set Callendar van Dusen coefficients to eliminate the sensor interchangeability error, makes a big difference. "It will realise an improvement in accuracy of up to 75% – far better than changing from Type B to Type A RTDs," Yao advises.

And she adds: "Transmitters are much smarter today. It's not just about diagnostics monitoring the transmitter itself; they check sensor health, track min/max for both process and ambient, and can detect abnormal process conditions through statistical process monitoring." PE